

THURSDAY, DECEMBER 7, 1882

RECENT RESEARCHES IN THE METAMORPHISM OF ROCKS

IN the heart of many mountain-ranges, and likewise spreading over wide hilly areas of the northern part of our hemisphere, lies the strikingly distinct series of rocks to which the name of The Crystalline Schists has been given. The passing traveller who knows nothing of geology cannot fail to be struck with their strange, crumpled and gnarled beds, through which streaks of white quartz wind and twist in a network of interlacing veins. Sheets of the naked rock often present a silvery sheen as sunlight falls across them, and this glistening aspect may be traced down in the minutest flakes of silvery mica that lie packed in parallel leaves throughout the mass.

No group of rocks has given rise to more discussion than the Schists. An account of the oscillations of opinion regarding their origin would form a curious and interesting chapter in the history of geological speculation. They have been looked upon as parts of the aboriginal crust of the planet—traces of the first solid film that formed upon its fiery surface. By one school of writers they are believed to be original chemical precipitates from the waters of the primeval ocean. By another they are treated as masses of sedimentary or other material which have been crystallised and altered into their present condition by a process to which the name Metamorphism has been given. Between these two doctrines, with their various modifications, the pendulum of geological opinion has vibrated for somewhere about a century, and vibrates still. In England and America indeed, owing mainly to the commanding influence of Lyell, the metamorphic theory has so entirely prevailed that most English-speaking geologists have come to accept it as a demonstrated truth, and to look back upon the Wernerian doctrine of chemical precipitates as a singular and happily obsolete vagary of the geological imagination. They have written text-books in which that doctrine is not even so much as honoured with an allusion to its ever having existed, though here and there a solitary protest has now and then been raised among us in favour of the other view, like that uttered by De la Beche as far back as 1834, and those of Dr. Sterry Hunt in later years. In Germany, on the other hand, the old Wernerian dogma has always had its staunch adherents, but in gradually diminishing numbers, the theory of the metamorphic origin of the crystalline schists having been warmly espoused there also by an ever-increasing body of observers.

For some years past what has been called the orthodox metamorphic doctrine has been called in question by various writers who have cast doubts on the observations which were believed to prove the fact that wide areas of rock, originally of fragmentary or detrital composition, had undergone a conversion into crystalline schists. The time-honoured doctrine of chemical precipitates, tricked out in the finery of modern chemical analysis, has been resuscitated and defended with the warmth of the most devoted partisanship. Within the present year, however, several memoirs have appeared which powerfully support

the doctrine of metamorphism, and as effectively oppose the rival hypothesis. The aid of the microscope, as well as of chemical analysis, has been invoked: new facts and arguments have been adduced, and the nature of the changes involved in metamorphism have been more clearly made known. Whether or not there may be any crystalline schists in the earliest or Archæan rocks of the earth's crust, which had their origin in the chemical precipitates of a primeval ocean, may remain a question for future discussion. But recent researches with all the manifold appliances of modern petrography demonstrate beyond the possibility of all further cavil, that ancient sedimentary strata have undergone such an alteration as to have assumed a more or less completely crystalline condition, that numerous silicates have been developed in them, often also with foliation, and that these changes are seen round bosses of granite and other eruptive masses (contact metamorphism), but also far more strikingly over wide regions where eruptive rocks cannot have induced them (regional metamorphism), and that in the latter case the alteration is always connected with evidence of enormous mechanical pressure of the strata. To one or two of the more important recent papers, brief reference may here be made.

The Silurian schists, with their fossils and remarkably compressed conglomerates in the Bergen district, have been made the subject of a remarkable memoir by Mr. Hans Reusch.¹ In this essay the author traces the passage from ordinary shales into fine phyllite-schists and mica-schists, in which crystalline aggregates of mica have been porphyritically developed. In some of the altered fossiliferous beds microscopic crystals of rutile and tourmaline have appeared. The fossiliferous limestones have been converted into marble, wherein, however, the organic forms can still be detected. The fossils which occur in certain mica-schists, and have been specifically determined, leave no doubt that the whole series of rocks belongs to the lower part of the upper Silurian system. Yet they include intercalated bands of gneiss, hornblende-schist, talc-schist, and other foliated rocks. The author connects the crystalline condition of these masses with the effects of the enormous mechanical pressure which they have undergone, as shown, for example, by the extreme flattening of the pebbles in some of the associated conglomerates.

The Silurian rocks of the Christiania district have long been famous for the illustrations they afford of the phenomena of contact-metamorphism. They have been subjected to a detailed investigation by Mr. W. C. Brögger, lately of the Geological Survey of Norway, and now Professor of Geology in the University of Stockholm. He has lately published what we hope is only an earnest of the valuable work we have yet to expect from him.² His monograph embraces the stratigraphy, palæontology, structure, eruptive rocks, and contact-metamorphism of the district. This last-named feature is more minutely traced out than has yet been attempted for that region, though only a beginning in the study has been made, Mr. Brögger deeming it

¹ "Silurfossiler og Pressede Konglomerater i Bergensskifrene." (Christiania: *Universitets program*, 1882). This memoir was recently noticed in these columns (*NATURE*, vol. xxvi. p. 567).

² "Die Silurischen Etagen 2 and 3 im Kristianagebiet und auf Eker." (Christiania: *Universitets program*, 1882).

better to publish his first results now than to wait for leisure to extend and complete them. He points out, as had already been done by Kjerulf and others, that while there is a general alteration as the rocks approach the eruptive masses of granite and syenite, the special type of alteration depends in each case upon the original capacity of the rock for metamorphism. He has traced the Silurian zones from their ordinary unaltered condition until they assume their most metamorphosed character against the granite, and he compares the chemical composition and microscopic structure of the unaltered and altered strata. He points out that certain bands of rock appear to be endowed with a remarkable capacity for withstanding the effects of metamorphism. Thus the *Dictyograptus*-shales may be observed close to the granite and in the midst of the most intensely-metamorphosed beds, yet comparatively little changed. They become paler in colour and perhaps somewhat harder and more compact, but their graptolites are as well preserved, down even to the minutest details, as they are at a distance from the contact-zone. The dark alum-shales are converted into hard compact bluish "Knotenschiefer" and chistolite-slates, still retaining their fossils. The chistolite crystals may even be seen traversing the graptolite-stems, which are otherwise as well preserved in these as in the ordinary unaltered shales. The remarkable development of silicates in the Christiania limestones, where these rocks have been converted into marble near the granite, has long been a classical instance of contact-metamorphism. Mr. Brögger gives some interesting observations of his own among these rocks. He notes the occurrence of recognisable fossils even in those parts of the marble where the silicates have been abundantly developed, and he points to the suggestive fact that where a fourth or fifth part of the marble is made up of red garnet, the latter mineral, in well crystallised rhombic dodecahedra, may be found inclosing the valve of an *Orthis calligramma*.

The alternation of comparatively little-changed graptolite shales with fine crystalline schists and forms of hornfels, which Prof. Brögger reports from so many localities, is a fact of great significance in relation to the problem of the origin of the crystalline schists. That the crystalline character has been superinduced upon what were once ordinary marine mechanical sediments admits now of no doubt. The extent of the change appears on the whole to depend on the one hand upon the liability of the rock to metamorphism, and on the other upon relative proximity to the eruptive rock. The preservation of organic remains in the altered bands is exceptional, and depends, according to our author, 1st, upon the greater permanence of the substance of the organisms, the chitin of the graptolites, for example, being apparently undistinguishable in the altered beds from the same substance in the ordinary shales; 2nd, upon the replacement of the hard parts of the organisms by mineral matter, either before or during the process of metamorphism; and 3rd, upon the filling up of the original cavities of the fossils by some mineral, as graptolites by pyrites, and the interior of brachiopods by wollastonite, or upon the inclosing of the organisms in a crystalline matrix as in the case of the impressions of shells in garnet, just referred to. But, as a rule, fossils disappear even from the most richly fossiliferous

bands as these are traced across the altered zone. Mr. Brögger modestly regards his observations as still too limited to warrant him in theorising on the phenomena of contact metamorphism. But the admirable methods he has followed, connecting in one broad microscopical and chemical research both the altered and unaltered condition of the same rock, mark a new starting-point for the further study of that great geological problem—metamorphism.

There is one further incidental but pregnant statement in this Memoir to which reference must here be made. So far back as the years 1875 and 1877 Prof. Brögger, in the course of his field-work in the Geological Survey of Norway, established the existence of graptolite-bearing beds among the crystalline schists of the Hardanger region. He now publishes some details of the section there visible, from which we learn that the graptolite band (*Dictyograptus-schiefer*) occurs among some black little altered alum-slates lying at the very base of the enormous series of crystalline schists forming the Norwegian highlands! The alum slates pass under some bluish quartzose sandstone, overlaid by a white impure marble (possibly the Orthoceratite limestone), which in turn is covered by greenish micaceous clay-slates (phyllites). Above these basement strata come more and more crystalline schists, comprising diorite-schists, hornblende-schists, garnetiferous mica-schists, foliated rocks of many varieties, and true gneisses—the two last mentioned rocks sometimes several thousand feet thick. We learn further that in 1877 the same observer, in harmony with Naumann's observations, established the fact that the enormous series of crystalline schists of the Norwegian mountains is younger than the second stage of the Silurian (or Cambrian) rocks of the Christiania district. He refers to his friend Mr. Reusch's discovery of Upper Silurian fossils from the crystalline schists of Bergen, as a confirmation of his former supposition that the whole of the vast succession of crystalline schists in the Norwegian mountains is a metamorphic series.

When we remember that on the opposite side of the peninsula similar primordial fossiliferous strata emerge from underneath the vast overlying schists and crystalline rocks of the Swedish uplands,¹ it is evident that an enormous area of regional metamorphism extends across Scandinavia. The close parallel between the structure of this region and that of the Scottish Highlands is one of the most striking facts in the geology of North-Western Europe. In both areas recognisable Silurian fossils occur at the very base of the vast metamorphic series, and the rocks become progressively more and more crystalline as they are traced from bottom to top.

A third remarkable paper by Père Renard, of the Royal Museum, Brussels, must be cordially welcomed as one of the most important contributions of modern petrography to the study of metamorphism.² It deals with a portion of the singular belt of crystalline schists which runs through the French and Belgian Ardennes. Dumont as, far back as the year 1848, published an account of these rocks, the significance of which that accurate observer fully perceived. He showed that they occur in his

¹ See A. E. Törnebohm, *Bihang till Svensk. Akad. Handl.*, 1873.

² "Les Roches Grenatiferes et Amphiboliques de la region de Bastogne," par A. Renard. *Bulletin du Musée Royal d'Histoire Naturelle de Belgique*, tome i. 1882.

Coblentzian division of the Lower Devonian rocks of that region, that they pass insensibly into ordinary sedimentary rocks, but towards their axis have been metamorphosed into more or less crystalline compounds in which various silicates (garnet, hornblende, mica, &c.) have been developed. He observed fossil plants and animals in some parts of these altered rocks. In one of his specimens of a rock full of garnet, Sandberger determined the presence of the characteristic Devonian shells, *Spirifer macropterus* and *Chonetes sarcinulatus*. Nothing can be more emphatic than the testimony borne by Dumont to the age of these rocks and the fact of their metamorphism. His essay upon them is hardly known to geologists generally, but it deserves to rank as one of the most precise and detailed contributions ever made by a field-geologist to the study of the phenomena of metamorphism.¹ His observations have been singularly confirmed by those of M. Renard. The metamorphic phenomena of the Ardennes are repeated on a greater scale in the extension of the Devonian rocks eastward into the basin of the Rhine, where they have been admirably described by Lossen,² whose pregnant memoirs on this and other geological problems deserve the closest study of the student.

Bringing all the assistance which chemical analysis and microscopical investigation now supply to the study of the origin of rocks, M. Renard, in the present communication, which fitly opens the first number of the newly-organised *Bulletin du Musée Royal de Belgique*, presents us with a detailed description of the garnetiferous and hornblendic rocks of Bastogne in the south-eastern portion of the Belgian Ardennes. It is impossible to give any adequate *résumé* of this memoir within the space here available. But attention may be directed to one or two of its more interesting features.

At the outset it should be noted that the band of metamorphosed strata here referred to occurs along a line of plication running in a general east-north-east and west-south-west direction; that it is not associated with any visible eruptive rocks, that it dies away into ordinary unaltered greywacke and shale on the outside, and becomes more and more crystalline towards the axis, until it presents the most intense metamorphism anywhere to be found in Belgium.

In subjecting to microscopic examination thin slices of some of these altered rocks, M. Renard noticed that the quartz-granules, presumably of clastic origin, have lost the liquid inclusions so generally found in the quartz-granules of old sedimentary strata. This fact (already observed by Sorby in the case of sandstone invaded by dolerite) seems to indicate that the sand-grains have not escaped the influence of the changes which have so profoundly affected the other constituents of the former sediment. The original carbonaceous matter of the rocks, now altered into graphite, is spread as a fine dust among the other constituents, generally coating the minerals, sometimes inclosed within them, frequently accumulated at certain points into black, brilliant irregular bands, occasionally as hexagonal flakes. This aggregation of the carbon recalls the way in which the graphite occurs in Archæan limestones. The garnet

crystals are marked by a singularly interesting arrangement of lines of crystalline inclusions disposed along the crystallographic axes of the inclosing crystals. In certain rocks the garnets (about three millimetres in diameter) are traversed by a series of paralleled joints or fissures which run in a given direction through all the crystals. These cannot, of course, be cleavage lines. They are attributed by M. Renard to fracture produced by mechanical pressure, and he remarks that the minute flakes interspersed through the ground-mass of the rock are oriented in the same direction.

Taking a general view of the microscopic structure of these rocks the author divides the constituent minerals into two groups: those which represent more or less distinctly the original sediment of which the rocks were formed, and those which have been subsequently developed by metamorphism. The quartz grains, for example, have preserved the closest resemblance to those of the ordinary normal arenaceous rocks of the lower Devonian series. The presence of graphite and anthracite likewise connects these crystalline masses with the sandy strata containing diffused carbonised vegetable matter. But on the other hand the crystalline structure and the presence of such minerals as garnet, hornblende, mica, titanite, and others connects these undoubtedly Devonian rocks with the crystalline schists of the Archæan series, as possibly both referable to the like series of physical and chemical changes.

M. Renard unhesitatingly discards the doctrine of direct chemical precipitation. He admits that the evidence of the physical structure of the country, as Dumont so well enforced, demonstrates that these crystalline rocks lie in the Devonian system and pass laterally into ordinary sedimentary accumulations. He further insists that the study of the minute structure of the rocks under the microscope confirms, in the most satisfactory manner, the view of that geologist that the actual condition of the masses has been produced by metamorphic action, in what way soever this action may have been induced. He connects the metamorphism with the proofs of great plication traceable through the altered Devonian rocks of the Ardennes. The mechanical action involved in the process would, he believes, predispose the sedimentary materials to a more or less complete recrystallisation. As it crushed them under the enormous pressure and partly was itself transformed into heat, it would set into active motion the chemical affinities of the various mineral substances. In this way sand might finally pass into quartzite, argillaceous mud into phyllade or phyllite-schist, sandy clay into more or less schistose micaceous quartzites; the calcareous matter would enter into combination to form the various lime-silicates so characteristic of these garnetiferous and hornblendic rocks; while the carbonaceous ingredient, losing some of its constituent elements, would separate out as graphite.

M. Renard's testimony to the theory of metamorphism is all the more valuable, as it has been extorted from him by the irresistible logic of facts against his own previous convictions. He has now furnished to this theory fresh evidence in its support, showing how well the observations by which it is established in the field are sustained by minute petrographical analysis. Every one interested in geological research will hope that the paper he has

¹ "Memoire sur les terrains Ardennais et Rhénan." *Mem. Acad. Roy. de Belgique*, 1848.

² "Geognostische Beschreibung des Taunus," &c. *Zeitschrift der Deutsch. Geo. Gesell.*, 1867, p. 509.

now published is only the first of a series on the same subject with which he will enrich the literature of the science.

ARCH. GEIKIE

HUMAN MORPHOLOGY

Human Morphology; a Treatise on Practical and Applied Anatomy. By Henry Albert Reeves. Vol. I. The Limbs and Perinæum. (London: Smith, Elder, and Co., 1882.)

THE author of this work is evidently very ambitious. In his preface he tells us that his primary wish was to produce a treatise in which he would deal thoroughly with the anatomy of man, and then compare his structure with that of other vertebrates, giving directions as to the dissection of the type-forms chosen in illustration. Further, being dissatisfied with anatomical nomenclature and classification generally, more especially with the terms at present in use in myology, he attempted a revision in this department.

As he proceeded with his task, however, he found that the labour, time, and knowledge necessary for carrying out so extensive a piece of work was too great, and that he had better relinquish his original idea and leave it for execution to more competent labourers.

But even after departing so far, and wisely as we think, from his first conception of what a student's text-book should be, he has found it necessary still further to withdraw from his original plan, and to excise much that he had written on anomalies of arrangement, various paragraphs on dissections which are out of the student's usual course to perform, and to reduce in quantity the sections on the practical applications of anatomy.

Had the author carried out his original idea of what a handbook for students and practitioners should be, he would have produced an encyclopædia of anatomy, and not a text-book for daily use.

But after all this renunciation of so much of the author's primary conception of what is required in a practical work on anatomy, sufficient is left to form a most voluminous treatise.

The volume before us extends to 719 large octavo pages. It comprises only the anatomy of the limbs and perinæum, and we are promised two additional volumes, each of between six and seven hundred pages, in order to complete the work.

It seems to us that the author even yet has not attained a proper idea of what the contents of a book should be, which, to use his own words, "is to be chiefly used *while the student is dissecting*." He has not sufficiently discriminated between the material that should find a place in a text-book of systematic anatomy and that which properly belongs to a practical treatise. We are quite in unison with him in the propriety of omitting all illustrations and detailed description of minute or microscopic anatomy. But we should have gone still further and cut out the historical sketch, the bibliography, the chapter on anatomical technics, which together would have subtracted between 60 and 70 pages from the volume. Also we should have condensed the descriptions and reduced in amount the sections on variations in the arrangements of the bones, muscles, and other soft parts.

A sketch of the rise and progress of anatomy, and a

copious bibliography are not required by the student at the dissecting table. On the other hand they are both interesting and useful in a systematic treatise. The variations in arrangement, more especially in the muscular and vascular systems, which have been observed and recorded, are so multitudinous, that they would require a special treatise for their description. What the student has to deal with in his ordinary work, are the commoner departures from the usually described arrangements, such as a third head to the biceps muscle, the high division of the brachial artery, the variations in the place of origin of the obturator, the profunda, the circumflex arteries, and so on. These and such like ought to find a place in all works on practical anatomy, but the more unusual forms are best reserved for such special treatises as Macalister's Catalogue of Muscular Anomalies, or Quain's description of the Arterial System, to which the student, who is desirous of obtaining a more intimate acquaintance with variations in structure, ought to be referred.

A knowledge of anatomical technics also is undoubtedly of primary importance to professed anatomists. But is one student in five hundred ever called upon to inject a body, either with a preservative fluid, or with a coloured arterial or venous injection? This work is done for him either by the demonstrator, or by the practical assistant in charge of the rooms. To introduce therefore into a work intended for medical students generally an account of methods, which they are never required to carry out, seems to us to be uncalled for.

The author directs especial attention to the number and quality of the illustrations. As regards their quality, with a few exceptions they are artistically rendered. But we think they are far too numerous, and by their number, and the size of many of the cuts, they have largely contributed to the unwieldy bulk of this treatise. Too many illustrations in a book to be used at the dissecting table are apt to draw the student's attention away from his part, and to make him rely upon the pictorial representation rather than on his own efforts to display the organ or region in the subject itself.

In our judgment a handbook of practical anatomy ought to be of such a size, that the student can without inconvenience carry it to and from his work. The instructions for the order of the dissections should be clear and concise. The descriptions of the parts should not be too elaborate. The illustrations should be well selected, with a view to guide the student in the method of his work, and to show him what he has to look for, and where it has to be seen. This treatise fails to comply in many respects with these conditions, and much as we may commend the author for his industry and good intentions, we are afraid that he has produced a work which will have only a restricted field of usefulness.

OUR BOOK SHELF

Common British Insects. Selected from the Typical Beetles, Moths, and Butterflies of Great Britain. By the Rev. J. G. Wood, M.A., &c. Pp. i-284. 8vo. (London: Longmans, Green, and Co., 1882.)

AFTER glancing through this book the question uppermost in our mind is: Why does it exist? The highly-ornamented cover, and the repeated title thereon, lead one